

# Evaluating Mitigation Options of Nitrous Oxide Emissions in California Cropping Systems

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California Air Resources Board  
Research Seminar  
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# Today's Talk

- Background on sources and mechanisms of N<sub>2</sub>O production from nitrogen fertilizer
- Results from field experiments testing N<sub>2</sub>O mitigation practices in 7 cropping systems
- N<sub>2</sub>O mitigation potential of management practices
- Conclusions
- Economics
- Resources for growers & consultants



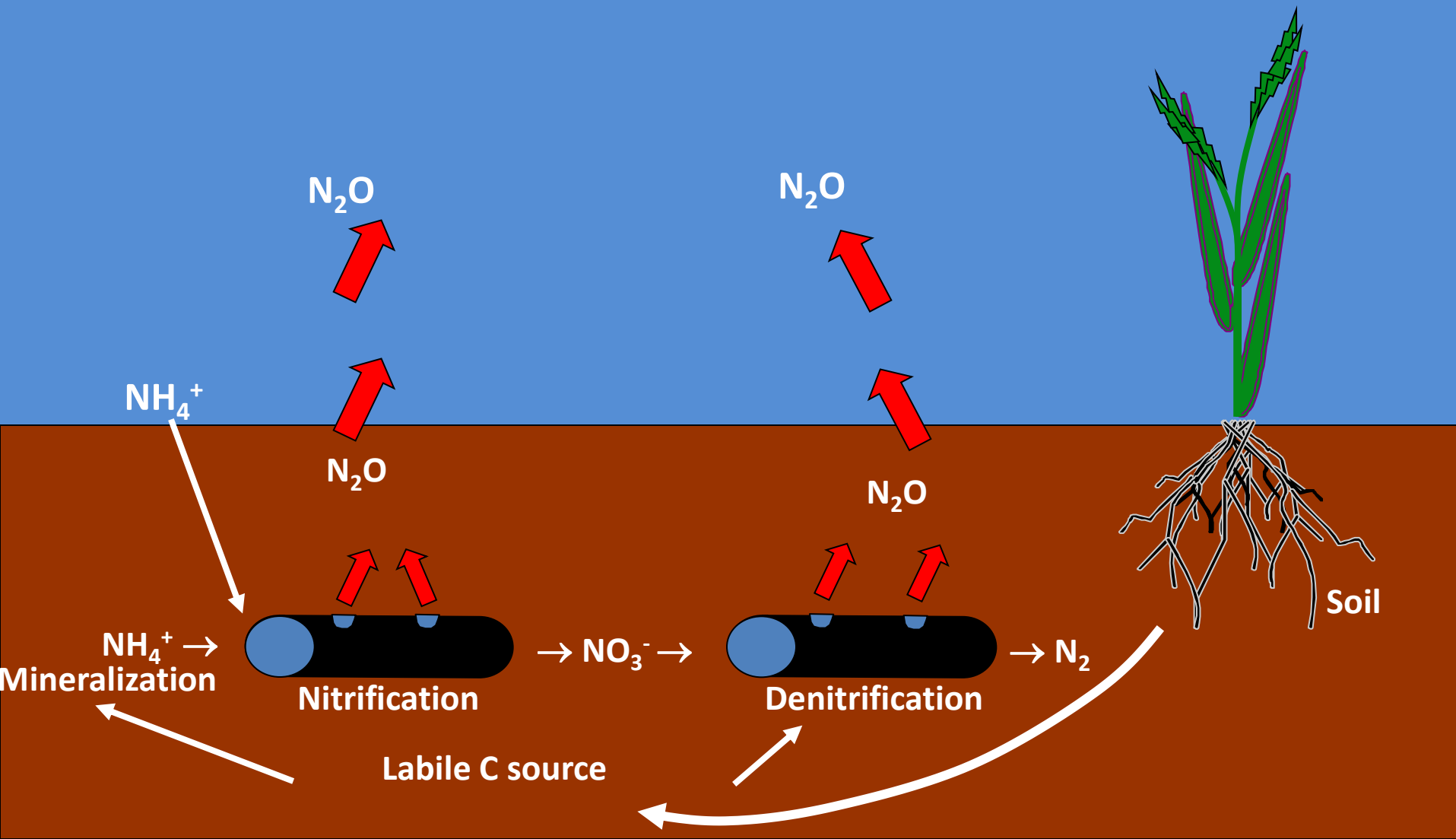
# Rationale for Research Approach

- Focus on management of nitrogen fertilizer and irrigation
- Strong correlation of  $\text{N}_2\text{O}$  emissions and fertilizer N rates
- Most N fertilizers are ammonia based and would therefore induce high rates of nitrification
- Short period (2-3 weeks) following N fertilizer applications often produces the majority of total seasonal  $\text{N}_2\text{O}$  emissions
- Need to understand mechanisms of  $\text{N}_2\text{O}$  production

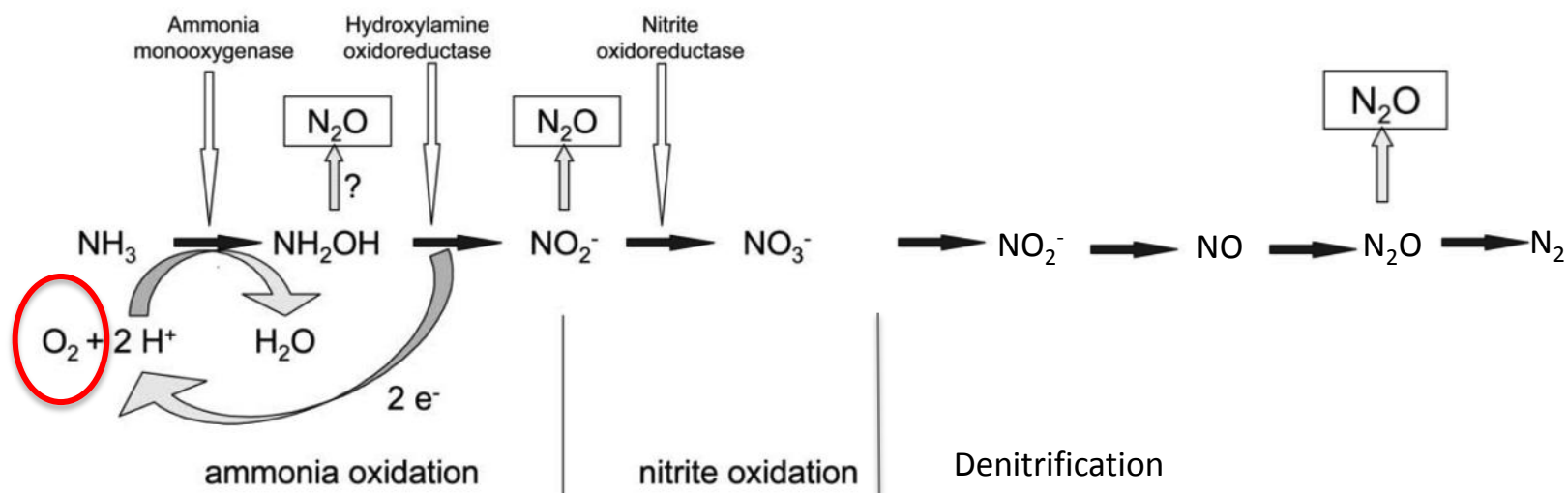


# Soil Factors affecting N<sub>2</sub>O production and emission

## The “Leaky Pipe Theory”



# $\text{N}_2\text{O}$ production through ammonia oxidation and denitrification pathways



# Controls on N<sub>2</sub>O Production

## ❑ Oxygen levels, regulated by moisture & carbon:

### ➤ **Low oxygen:**

- Microbes produce N<sub>2</sub>O during nitrification in addition to N<sub>2</sub>O from denitrification.

### ➤ **Anaerobic conditions:**

- Only denitrification, with N<sub>2</sub>O production rates increasing by an order magnitude

## Ammonia oxidation pathways and nitrifier denitrification are significant sources of N<sub>2</sub>O and NO under low oxygen availability

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# N<sub>2</sub>O Mitigation Potential / Hypotheses

Mitigation strategies with focus on managing NH<sub>4</sub> and O<sub>2</sub>:

## 1. Controls on nitrification

- Nitrification inhibitors slow down ammonia oxidation
- Choice of fertilizer: Pure ammonia vs. mixtures
- Concentration of N fertilizer in soil
  - Evidence from field experiments: Anhydrous ammonia causes higher N<sub>2</sub>O emissions than other N fertilizers
  - Addition of NH<sub>3</sub> increases soil pH, nitrification rates, and the potential for nitrite accumulation
  - Ammonia oxidation consumes O<sub>2</sub>





# N<sub>2</sub>O Mitigation Potential / Hypotheses

## 2. Keeping soils aerobic lowers N<sub>2</sub>O production

- Avoiding water logging
- Drip irrigation
- Maintaining soil porosity through organic matter additions







# Field Experiments

- ☐ ***N Fertilizer formulation:*** Corn
- ☐ ***Nitrification inhibitors:*** Corn, SDI tomatoes, wheat , almonds
- ☐ ***Fertilizer placement:*** Corn
- ☐ ***Drip irrigation:*** Corn, alfalfa, lettuce
- ☐ ***Organic management:*** Tomato
- ☐ ***Cover crops:*** Grapevines

# Corn: Fertilizer N Source and Nitrification Inhibitors

- ☐ 3 Fertilizers with varying ammonia:nitrate composition
- ☐ 2 Urease and nitrification inhibitors (AgrotainPlus™)
- ☐ Soil type: Reiff loam

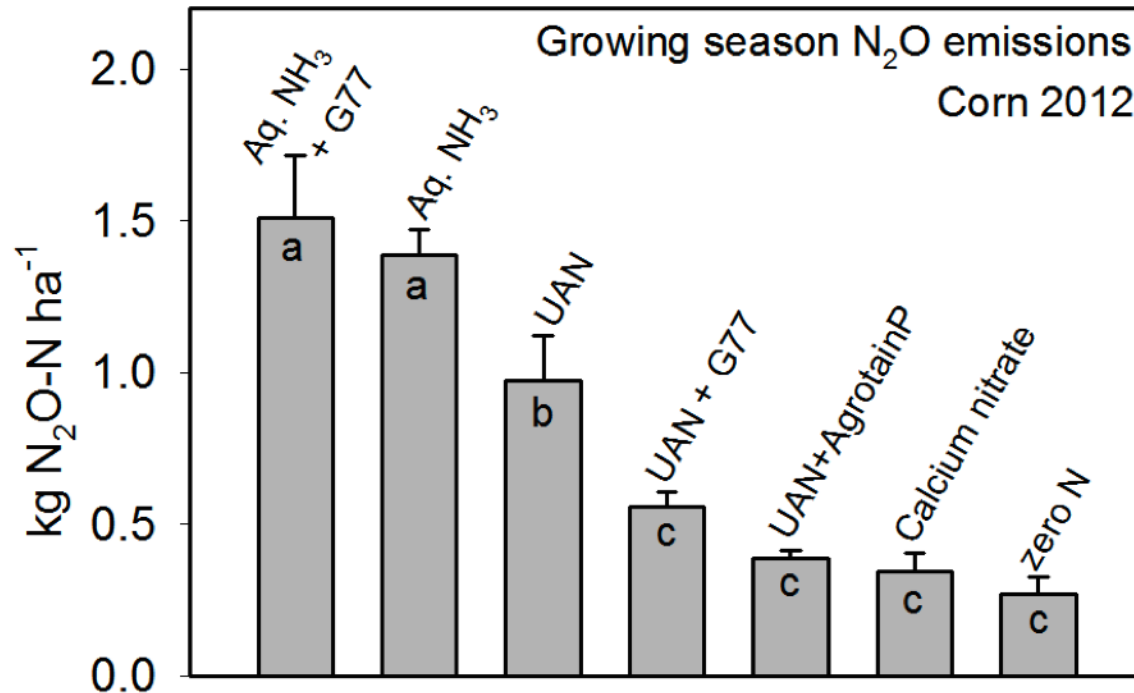


## Gas flux measurements:

- ☐ Static chamber technique
- ☐ 3 different chamber locations within each replicate plot (n=3):
  - Furrow
  - Shoulder
  - Bed
- ☐ Gas chromatography for analysis of chamber air



# Corn: Fertilizer N Source and Nitrification Inhibitors



- ❑ Furrow irrigated corn, fertilized with  $222 \text{ kg N ha}^{-1}$
- ❑ Nitrification inhibitor: Dicyandiamide (DCD)



# Corn: Treatments



Urea ammonium nitrate (UAN) fertilizer application in Stockton clay soil

- ☐ Nitrification inhibitor
- ☐ N Fertilizer placement
- ☐ N rate trial
- ☐ Subsurface drip irrigation in adjacent field

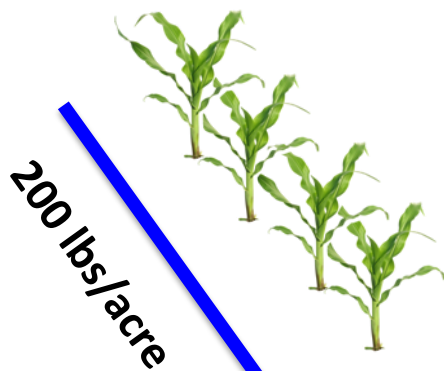




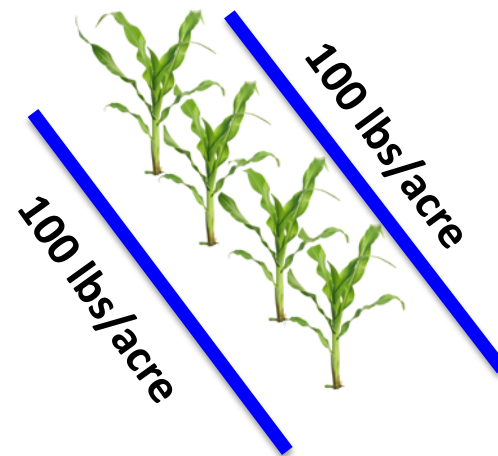
# Corn: N Fertilizer Placement



❑ One-band vs. two-band application of UAN fertilizer

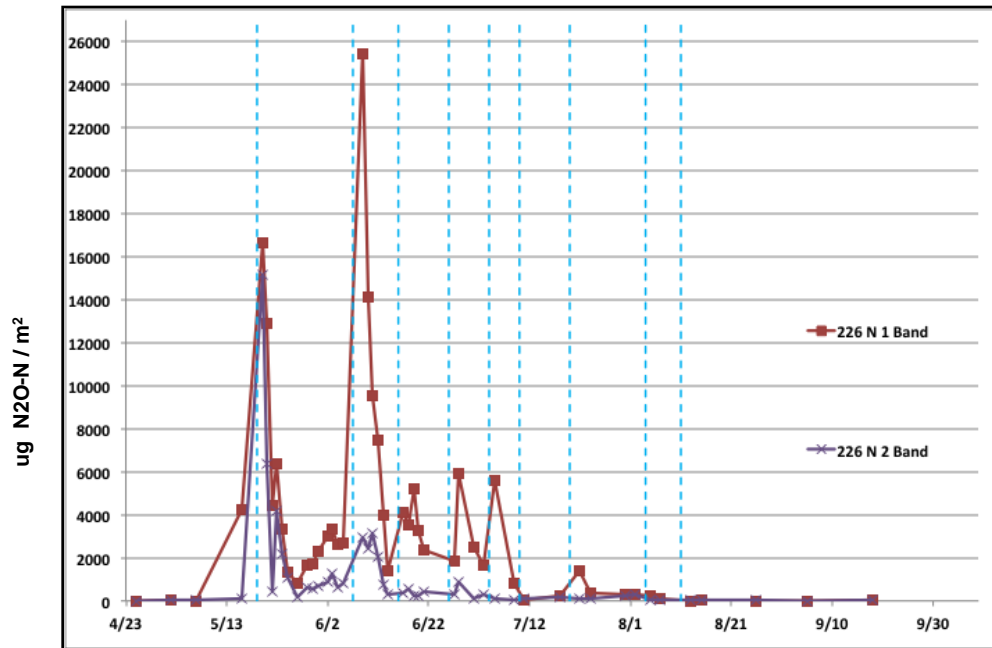


VS.



# One-Band vs. Two-Band UAN Application in Corn

Daily  $\text{N}_2\text{O}$  flux in furrow-irrigated corn fertilized with UAN

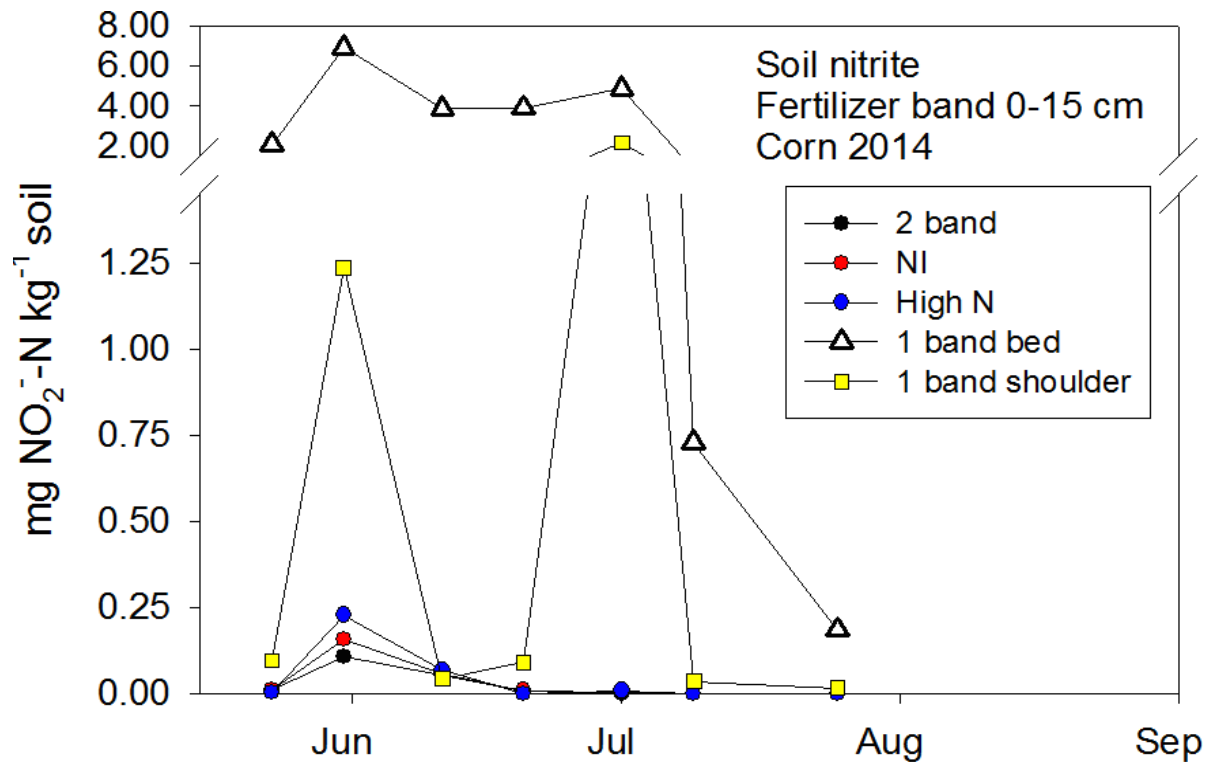


Daily  $\text{N}_2\text{O}$  fluxes were elevated for weeks when side-dress N was applied in one band (red symbols), rather than in two bands.



# One-Band vs. Two-Band UAN Application in Corn

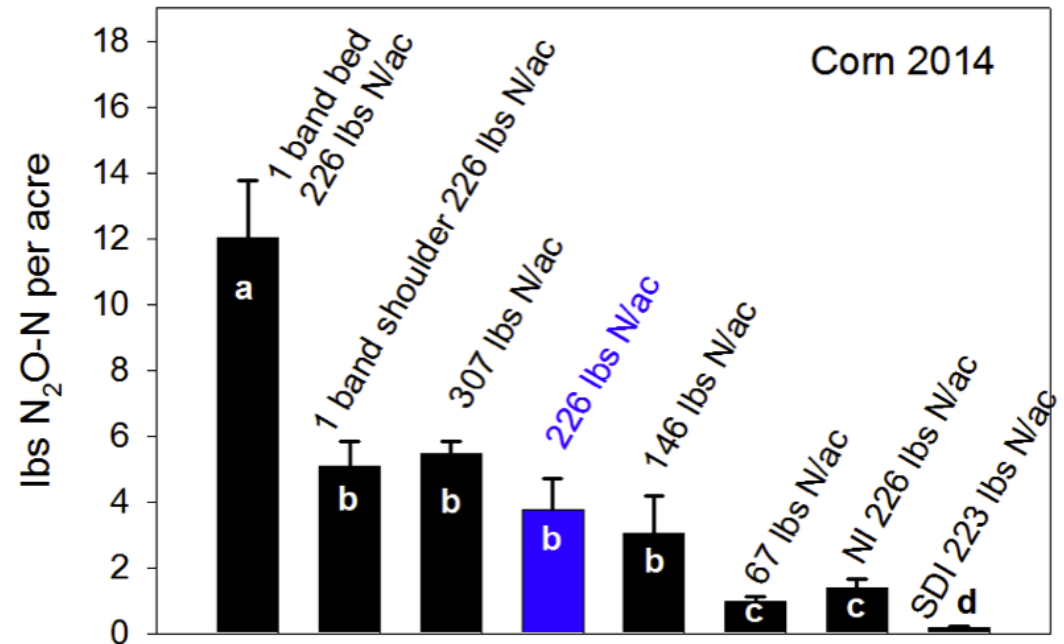
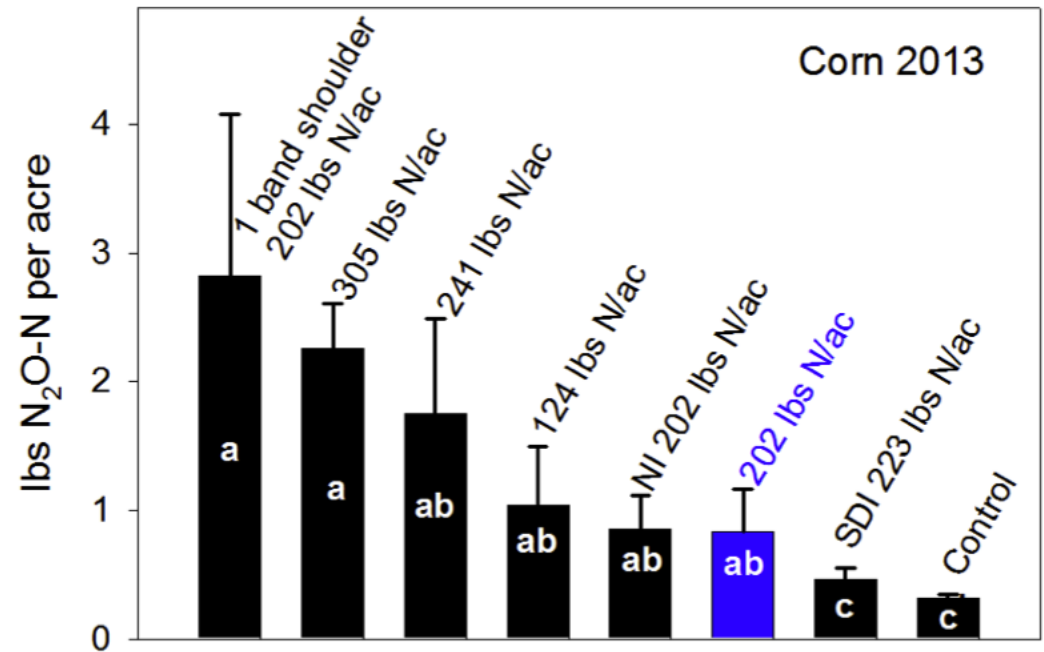
Soil nitrite concentrations





# Corn: Results of Trials in Grower Fields

- ☐ Highest N<sub>2</sub>O emissions in 1-band treatments
- ☐ Lowest N<sub>2</sub>O fluxes in SDI
- ☐ Nitrification inhibitor effective in one of two years
- ☐ No effect of nitrification inhibitor on yields or plant N uptake



# Alfalfa

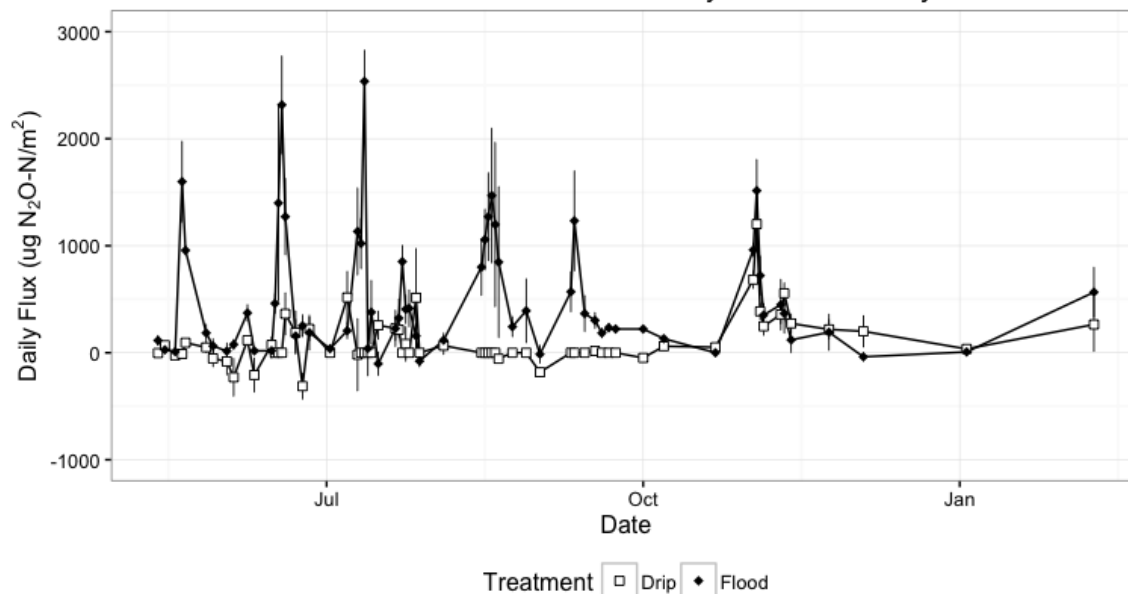
## Subsurface Drip vs. Flood Irrigation



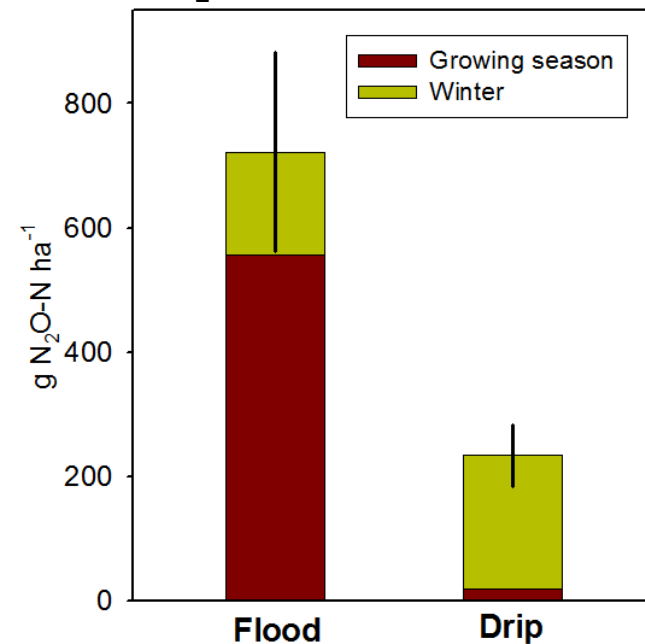
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# Alfalfa: Subsurface Drip vs. Flood Irrigation

Alfalfa Nitrous Oxide Emissions: May 2015 - February 2016



Annual and seasonal  $\text{N}_2\text{O}$  emissions



# Lettuce: Sprinklers and Surface Drip Irrigation

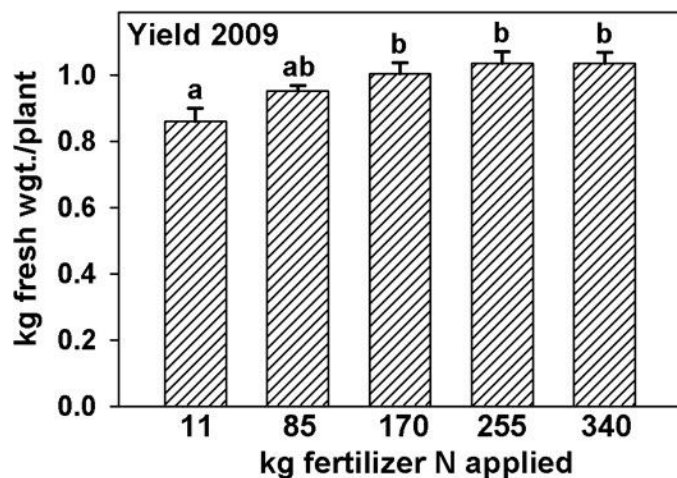


Surface drip irrigation after thinning



# Lettuce

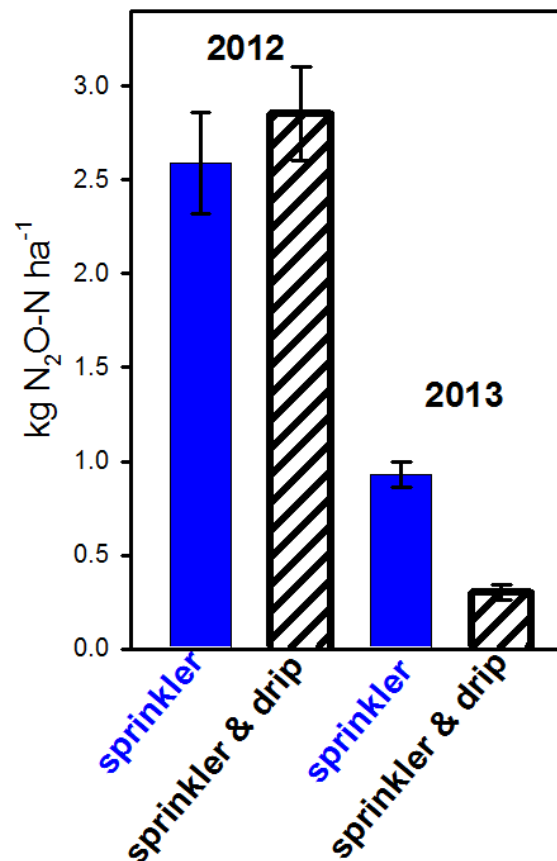
## Lettuce Yields & Crop N Removal



## Crop N off-take:

	kgN/ha
11	98.5
85	114.8
170	136.2
255	148.8
340	159.1

## Seasonal N<sub>2</sub>O emissions



**2012:** N fertilizer application 336 kg N/ha  
**2013:** N fertilizer application 234 kg N/ha



# Testing Nitrification Inhibitors in Tomato, Wheat, and Almonds





# Wheat



January 2014



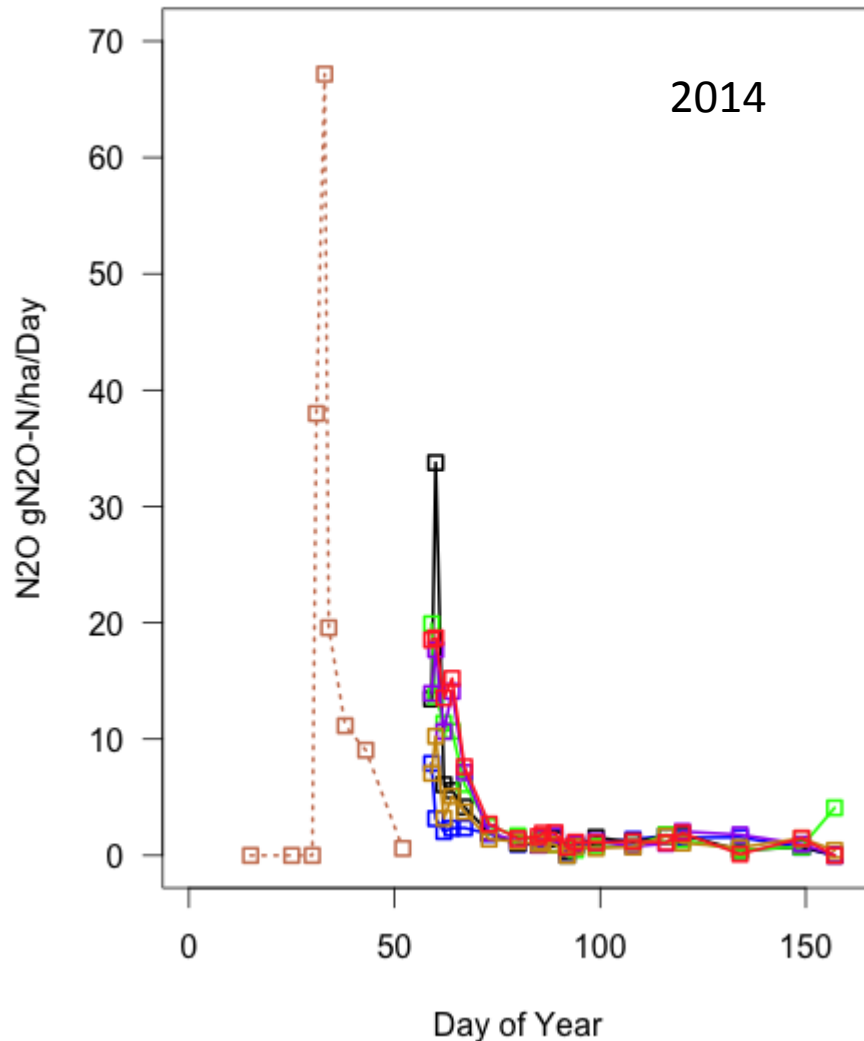
February/March  
2014





# Wheat

## Soil Nitrous Oxide Fluxes



1

g N<sub>2</sub>O-N ha<sup>-1</sup>

January irrigation: 576

Feb/March rainfall:

Control 135

SuperU 140

CaNO<sub>3</sub> 196

Nitrapyrin 212

Slow release 233

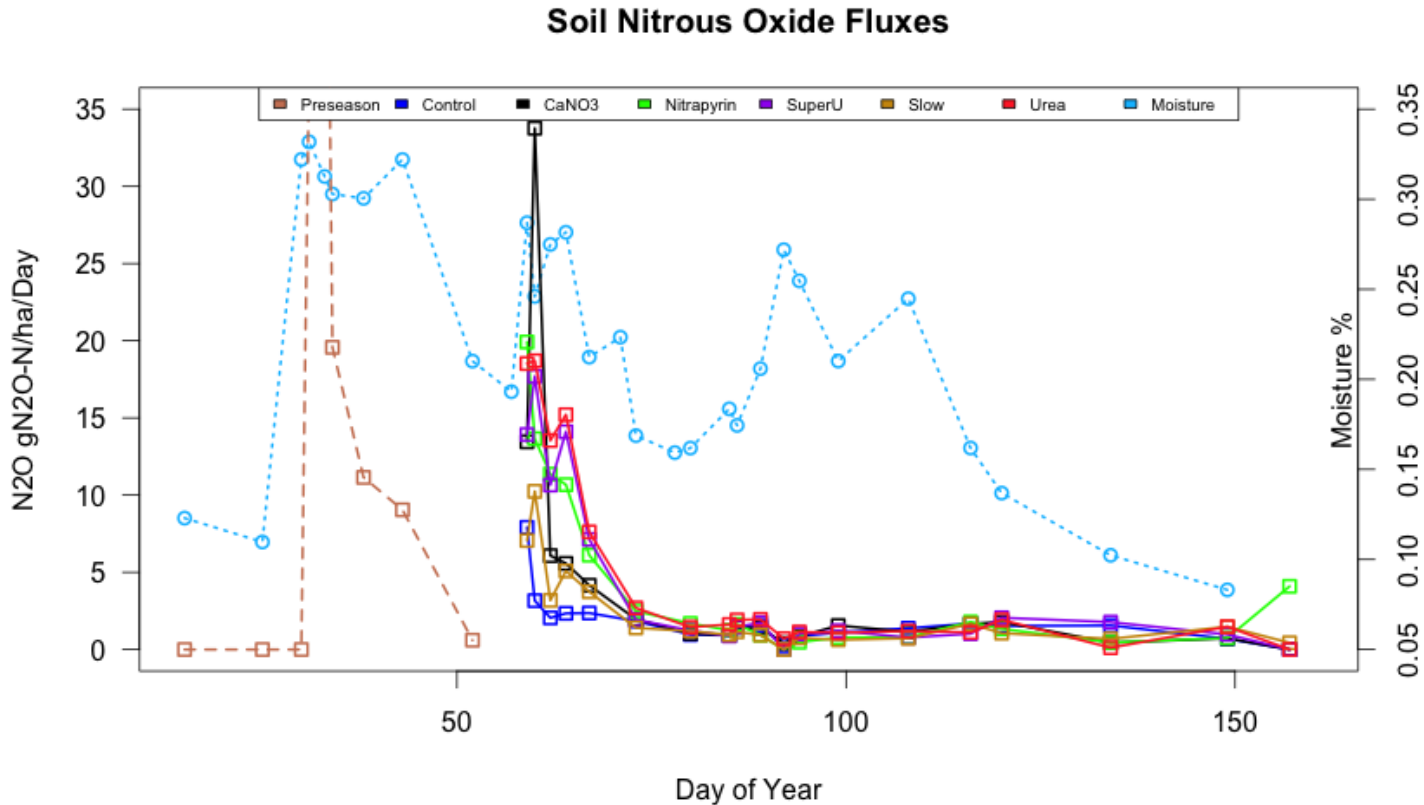
Urea 445



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# Wheat

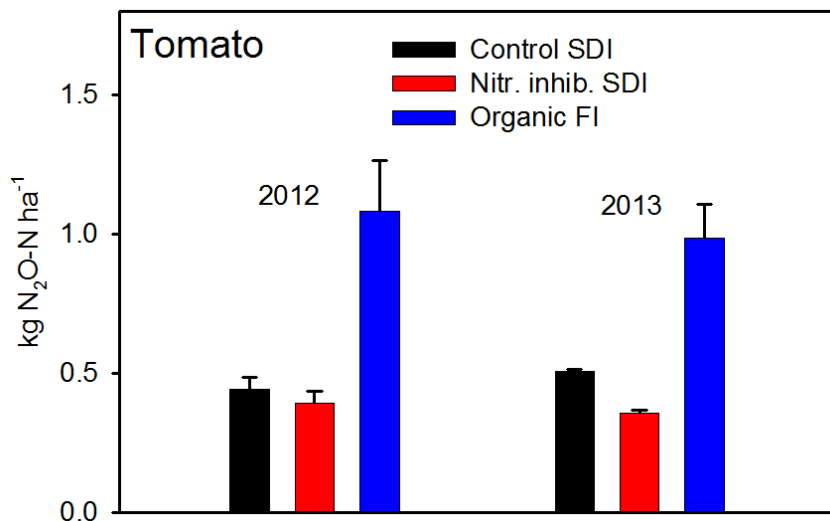


- ❑ High yields (4.3 – 4.7 U.S. tons/acre)
- ❑ 75% top dress N fertilizer recovery in plants

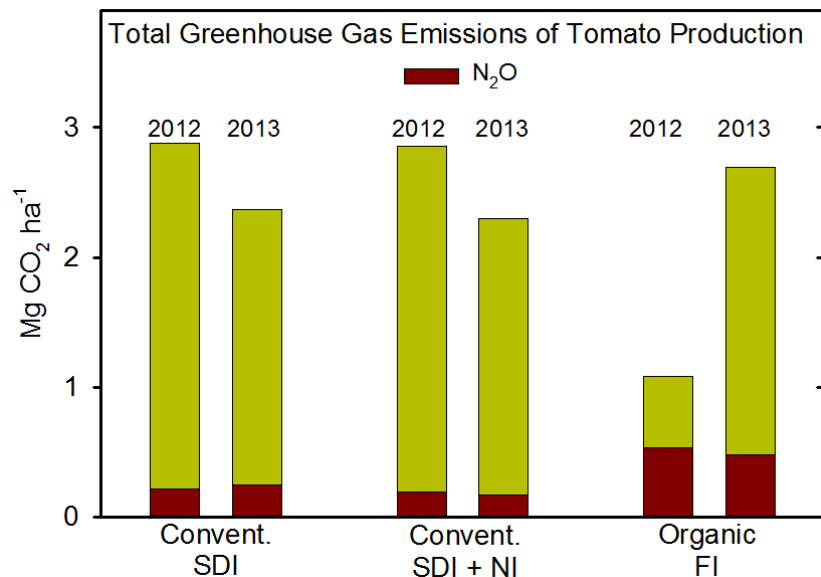


# Tomato: Conventional & Organic Management

## Seasonal $N_2O$ emissions



## Total GHG emissions



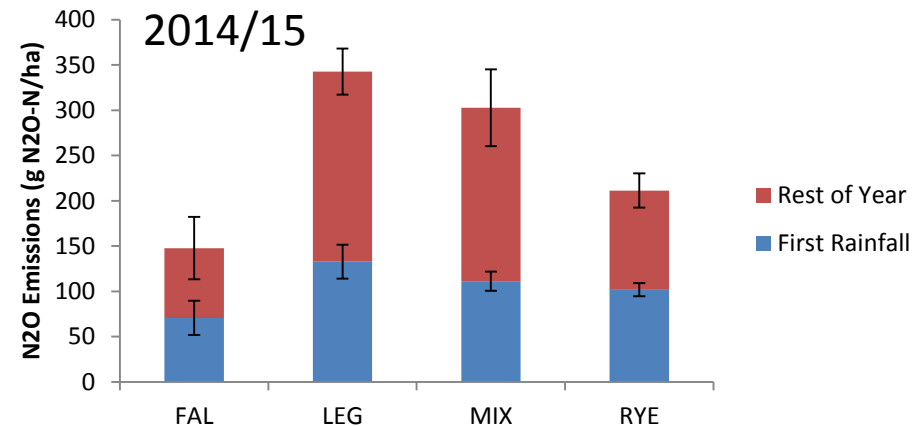
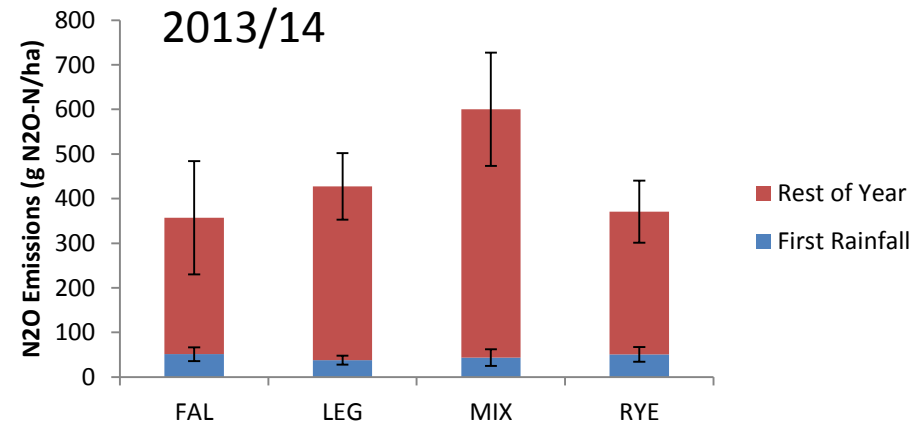
## Treatments:

1. Conventional SDI control
  2. Conventional SDI nitrification inhibitor
  3. Organic, furrow irrigated
- Brentwood silty clay soil



# Vineyard

## ❑ Effect of winter cover crops on N<sub>2</sub>O emissions triggered by first rainfall



# Summary

## Reduction in N<sub>2</sub>O Emissions with Mitigation Practice

kg CO<sub>2</sub> eq. ha<sup>-1</sup> reduction

### **Nitrification inhibitors**

Corn	280 - 1245
Tomato	30 - 72
Wheat	79 - 141
Almond	0

### **Subsurface drip vs. furrow- or flood irrigation**

Corn	265 - 1300
Tomato	492 - 670
Alfalfa	228
Lettuce (sprinkler/drip vs. sprinkler)	295

### **Fertilizer formulation**

Anhydrous ammonia vs. ammonium sulfate	300
Aqua ammonia vs. UAN	197

### **Placement**

Two-band vs. one band bed UAN application	4500
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# Summary

kg CO<sub>2</sub> eq. ha<sup>-1</sup> reduction

## **N use efficiency**

Recommended vs. excessive N rate

Corn	566 – 1574
Lettuce	136 – 384
Tomato, furrow-irrigated	1063 – 1307



# Conclusions

- ❑ Subsurface drip irrigation reliably reduces N<sub>2</sub>O emissions.
  - Adoption is driven by economics, preferred for high-value crops
  - Subsurface drip may not be optimal for every cropping system
- ❑ Nitrification and urease inhibitors show promise for reducing N<sub>2</sub>O
  - Know-how needed to use optimally
  - We did not see any differences in N use efficiencies or yields
- ❑ Spatially concentrating N fertilizer is not recommended
- ❑ Concentrated ammonia fertilizers (anhydrous, aqua) likely produce higher emissions than other formulations
- ❑ To improve N use efficiency and encourage correct N fertilizer additions, regular pre-plant soil sampling is recommended





# Economic Considerations

- Large installation costs for subsurface drip irrigation and increasing maintenance costs over time. Investment will be made if high-value crops in the rotation, e.g. processing tomatoes:
  - Operating cost \$2700 per acre
  - Cost of production \$62 per ton tomatoes
  - Revenue (2014) \$83 per ton tomatoes
- Typical urease and nitrification inhibitor application \$ 50/ ha
- \$ 12.69 per Mg CO<sub>2</sub>eq. (June 9, 2016) in California
- Soil sampling : Several hundred \$ per field (about \$10 per acre), but savings in fertilizer costs can outweigh this expense
  - Typical Fertilizer costs (SDI tomatoes) \$195 per acre

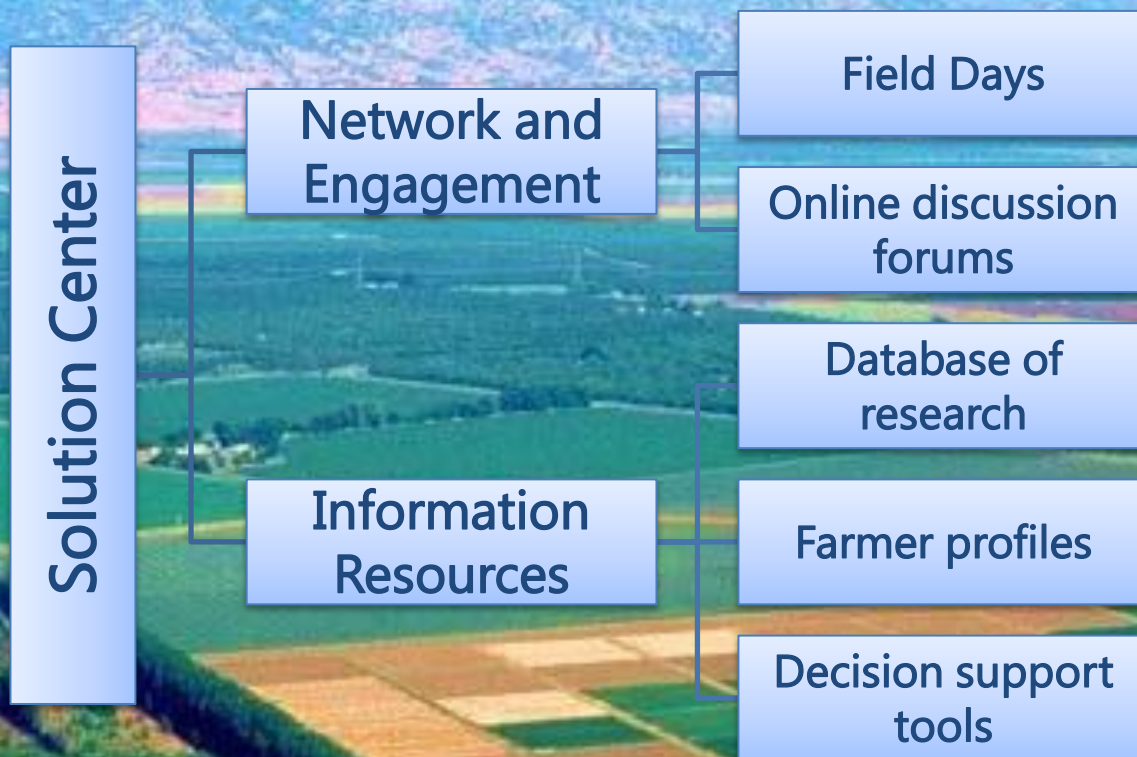




# Solution Center for Nutrient Management

University of California  
Agriculture and Natural Resources

[http://ucanr.edu/sites/Nutrient\\_Management\\_Solutions/](http://ucanr.edu/sites/Nutrient_Management_Solutions/)



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## California Fertilization Guidelines

These guidelines are based on research results from studies carried out in California and elsewhere. For an optimal fertilization program, site-specific information needs to be taken into account. A discussion about site-specific adjustments can be found [here](#).

### Additional Information

#### Soil and Plant Tissue Sampling

Soil Test Sampling Instructions

Sampling for Soil Nitrate Determination

Soil Sampling in Orchards

Plant Tissue Sampling

#### Resources, Links

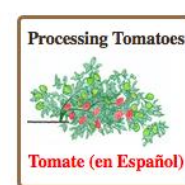
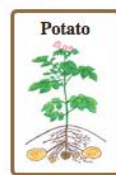
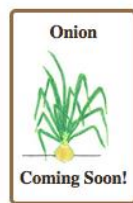
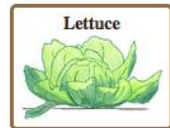
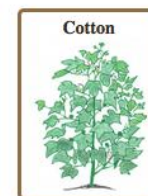
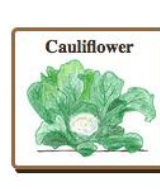
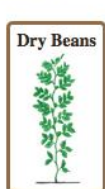
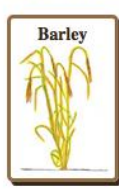
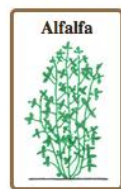
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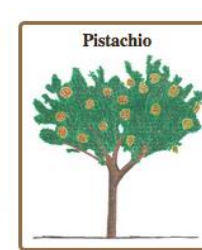
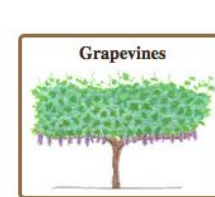
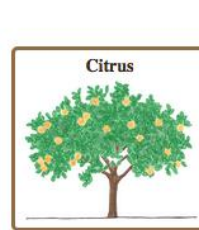
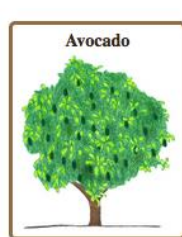
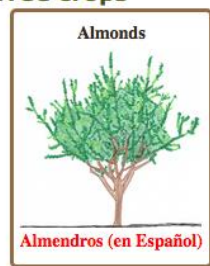
#### Nitrogen Partitioning and Seasonal Uptake Curves

#### A Discussion about Site-Specific Adjustments

### Field crops and vegetables



### Tree crops



# Acknowledgements



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